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Dragonflies and climatic change - recent trends in Germany and Europe

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Abstract

In this paper the trends of dragonfly expansions during the last decades in Germany and Europe are summarized. It is shown, that there is a general expansion of many species to the north: Mediterranean species expanded to Central and Northern Europe, whereas some African species expanded to Southern Europe, some are even new to the continent. In general this means an increase of biodiversity, but looking at the ecological effects, in the medium term a decrease can be expected for mooreland and alpine species. Dragonflies can be regarded as a good indicator group for climatic change. Already now in some areas or regions negative effects on waters bodies and their dragonfly communities can be observed and more will occur if e.g. temperature rises or precipitation decreases. The consequences for nature conservation strategies – such as the NATURA 2000 network – are outlined and the general need for monitoring programmes is emphasised.

Keywords

dragonflies, climatic changes, indicators, risks, ecological effects, nature conservation, monitoring

Introduction and some definitions

Since the 1990ies the discussions on the effects of climate change became increasingly intensive, in ecology as well as in nature conservation (e.g. Gates 1993). Climate change is now regarded as one of the most important factor threatening species, habitats, ecosystems and biodiversity in general (e.g., Lovejoy and Hannah 2005; IPCC 2007a,b; Settele et al. 2010a, 2010b; EEA 2010).

Subsequently an overview is given on the reactions of dragonflies following those climatic and habitat changes which have so far been observed. Finally some conclusions for the protection of dragonflies are drawn.

Oscillations versus Trends

The changes of species` ranges as a result of climatic changes – here the main focus is on expansion – is a normal process, but it is important to differentiate between "oscillation" and "trend".

Oscillation can be described as a regular movement from one side to the next or a regular cycle and for a species in a new area it means "coming and going". E.g., if the weather in some years is favourable for the species, it expands and later on, in years with unfavourable weather, it retreats its range back to the former extension.

A *trend* on the other hand is a gradual development – maybe including some small oscillations – but in general resulting for a species in "coming and staying" in a new area and a constant expansion of the species` range.

Tipping points, scenarios and ecosystem services

Tipping points are described as the moment, when an object or situation is displaced from a state of stable equilibrium into a new, different state; such a shift from one state to another is irreversible.

A scenario is a postulated sequence of possible events based on assumptions. In this context it is for example the increase of carbon dioxide emissions or temperature, as a consequence of economic growth, as it is worldwide coupled with the consumption and burning of fossil energy. It is projected on the basis of current circumstances and trends.

Natural as well as man-made ecosystems supply humans with a lot of different resources and processes and all these benefits are defined as ecosystem services, such as pollination, drinking water or the decomposition of organic material. Natural systems in particular are increasingly influenced and altered by human activities.

The expansion of southern species in Germany and Europe

Example: the expansion of *Crocothemis erythraea* in Germany and Europe

The best example of the expansion of a dragonfly is without doubt the Scarlet Darter (*Crocothemis erythraea* (Brullé, 1832), see fig 1). In the literature in Germany and other countries north of the Alps this species still was described as a "Mediterranean species",

Figure 1. A male of the Scarlet Darter (*Crocothemis erythraea*). Foto: J. Ott

until about three decades ago, also being regarded as a typical vagrant species which only in rare occasions could be observed breeding in northern countries (e.g. Jurzitza 1978).

But then it became permanently indigenous in Germany, in the beginning only in southern federal states and in the lowlands along the Rhine River (Ott 1988, 1996). In the following years it was expanding to the north – finally reaching the border to Denmark in 2009 – and it was registered also in higher altitudes (Ott 2001a, 2007a, 2010a, see also fig 2). Its expansion corresponded with the increase of temperature, even if it is still unclear which factor(s) is (are) the dominating one(s) (e.g. maximum temperature, mean temperature, duration of sunshine).

The positive temperature effect is also underlined by the observation, that in the extremely warm year of 2003 the species obviously had a second generation (Horn 2003).

This expansion was not only registered in Germany, but also in other European countries which is summarized for some countries in the following table (Table 1).

A comparable expansion was noted also for other European countries, like for the Ukraine (see Khrokalo, 2010) and Luxemburg. In the Ukraine – beside other Mediterranean species – *Crocothemis erythraea* expanded all over the country in the last three decades. In Luxemburg the species was first discovered in 1986 while in 2005 it was present in 17 % of the grid cells (Proess 2006).

This expansion in Europe over the last decades finally can be regarded as a clear *trend* of expansion rather than only an oscillation of its range.

Some more examples: other species expanding their range in Germany

The example of the Scarlet Darter, a very striking species which is easy to detect at the water (see fig. 1) is not the only one. Other “southern” species also expanded their

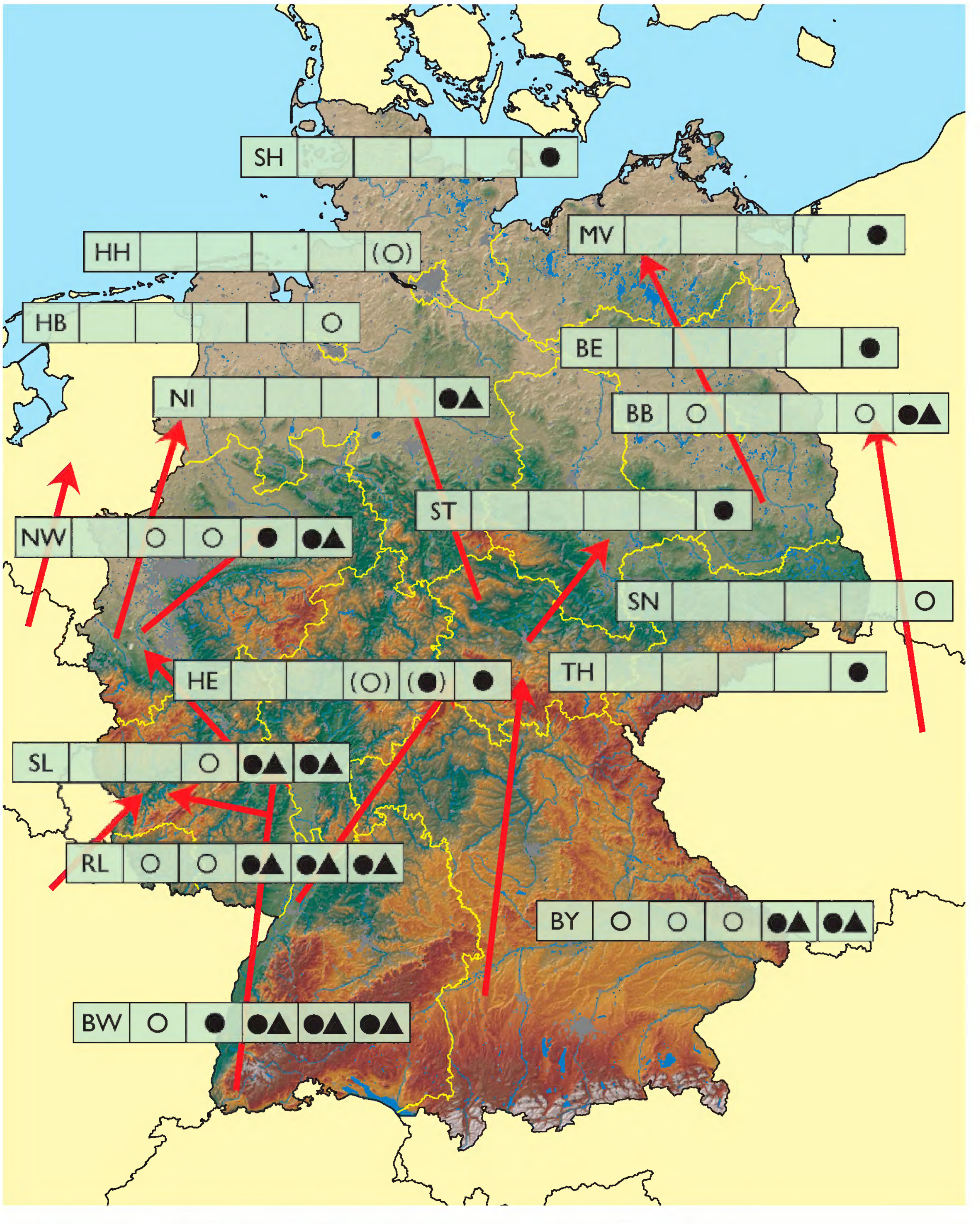

Figure 2. Expansion of the Scarlet Darter in Germany (Ott 2007a, updated)

range in Germany northwards or invasions were noted much more frequently. Besides species like *Erythromma viridulum* (Charpentier 1840), *Orthetrum brunneum* (Fonscolombe 1837) and *O. coerulescens* (Fabricius, 1798) which crossed Germany already some time ago or became much more abundant (see Ott 2001a, 2008a), some more recent examples are subsequently presented.

Anax parthenope Selys, 1839:

The species presently expands its range in central and north-east Germany (e.g. Mauersberger et al. 2002), but also in regions where it has previously established new populations it becomes more abundant. E.g., in some gravel pits in the Rhine Valley

Table 1. Expansion of *Crocothemis erythraea* in some European countries.

country	time	source	situation
France	1960–1986	Dommanget (1987)	known from 28 French *departements* out of 96, more frequent in the south and very abundant in the Mediterranean
	< 2000	Grand and Boudot (2006)	not known from 3 *departements*, in 18 rare or very rare, but in all the other *departments* common to very common, also in central and northern ones
The Netherlands	< 1983	Geijkens and van Tol (1983)	only one sure record from 1959 and 2 others from 1967 and 1968 have been confirmed
	< 2002	NVVL (2002)	steady expansion after the first population was discovered in 1993, thereafter several populations present and increasing
	< 2007	Bouwman et al. (2008)	between 1997 and 2007 registered in more than 250 localities (= 5 x 5 km grid cell)
UK	< 1995	Hammond (1977), Merrit et al. (1996)	no observation ever
		Parr (2005, 2008)	first record in 1995, thereafter until 2005 in total 6 accepted records confirmed, some others probable, regularly observed as breeding populations on the Channel Islands (e.g. 2007 on Jersey) and breeding
Poland	< 1989	Bernard et al. (2009)	only 6 records, possibly only one of them from an indigenous population
	> 1990	Bernard et al. (2009)	broad expansion, species now widespread (even if still rare on the national scale) and indigenous up to 52° 38`N, in total ca. 50 localities
Czech Republic	1950–1989	Dolny et al. (2008)	found in 5 grid cells (out of 659)
	1990–2007	Dolny et al. (2008)	found in 105 grid cells (out of 659)
	2008–2009	Dolny pers. comm.	found in another 10 grid cells

near Ludwigshafen and north of Worms it is now more abundant than *Anax imperator* Leach, 1815, whereas in the mid 1980ies *A. parthenope* was very rare in this area and *A. imperator* was the dominating aeshnid in the summer (Ott unpubl. data).

Aeshna affinis Vander Linden, 1820:

A constantly increasing number of observations has been confirmed in the last two decades. In the Rhine Valley and Lower Saxony the species became, for the first time, indigenous in the mid 1990ies (Ott 1997; Drees et al.1996), later on in 2000 also in north-eastern Germany in the federal state of Brandenburg (Brauner 2005), where up to 2005 it was found breeding in 32 waters.

Boyeria irene (Fonscolombe, 1838):

This Mediterranean species inhabiting mainly running waters, but also big lakes, in Germany was found for the first time in 2002 and then again in 2004 (Schmidt 2005). As also in France northward expansion is registered (up to the region Champagne-Ardenne in 2006: Ternois 2008), without any doubt the species sooner or later will

populate more waters. Whether the new German population in Lower Saxony (river Ötze) - hundreds of kilometres north from the known sites – could already be regarded as a part of an expansion, needs further investigation (Clausnitzer et al. 2010).

Coenagrion scitulum (Rambur, 1842):

Also this damselfly is expanding its range and was found in Rhineland-Palatinate for the first time in 2006 (Glitz 2008), where in some areas it expanded very much (Lingenfelder 2008). Also it was newly discovered for Bavaria (Karle-Fendt 2006). In North Rhine-Westfalia, where it also was rarely seen in the past decades, it is now much more abundant and shows increasing populations (Grebe et al. 2006).

Beside these species mentioned above, several more Mediterranean species recently became much more abundant and even common in Germany, like *Sympetrum fonscolombii* (Selys, 1840) or *Orthetrum brunneum* and *O. coerulescens.*

It shall be noted that nearly all "southern" species expanding in Germany showed the same pattern: expansions show a clear northward direction and often individuals or populations are also found in higher altitudes.

On the other hand, no "northern" species showed a comparable expansion to the south. There are also some expansions, e.g. by *Gomphus vulgatissimus* (Linnaeus 1758) or *Gomphus flavipes* (Charpenties 1825), but this might rather be a consequence of a better water quality in rivers, than the effect of a change in temperature or climate. Whether the new and remarkable expansion of *Leucorrhinia caudalis* (Charpenties 1825), in northern Germany (Mauersberger 2009; Deubelius and Jödicke 2009) is an effect of climatic change definitely needs further investigation.

The effects on waters: changing climate – changing communities?

A practical example: the "Kolbental" monitoring-project

The changes in the fauna of an area can only be described in detail, if these changes can be followed permanently and over an extended period. This is the case for example in the "Kolbental" monitoring-project near Kaiserslautern (Ott 2001b). The nature reserve "Täler und Verlandungszone am Gelterswoog" (valleys and silted-up zone near lake Gelterswoog) is a ca. 55 ha wetland complex with a mosaic of very diverse biotopes (meadows, forests, abandoned land, lentic and lotic waters etc.). This reserve consists of 3 valleys with 11 standing waters (so called "Wooge") and some of these biotopes are protected according to national or international laws (EC habitat's directive: e.g. dystrophic waters and transition mires, Natura 2000-code: 3160 and 7140).

In this area a regional agency (ZWW/TWK) planned to extract about one million cubic meters of ground water for drinking water supply. This permission was only given by the regional authority under the prerequisite, that the agency is able to proof

the sustainability for the environment by means of hydrological and ecological monitoring. These two monitoring projects started in 1998, and the ecological monitoring consists of the collection and evaluation of abiotic data (climate, soil humidity, water analysis etc.), as well as investigations on the vegetation and the fauna. As indicator taxa for the monitoring project carabid beetles, butterflies, grasshoppers and dragonflies were chosen.

Whereas in the beginning flora and fauna remained relatively constant, dramatic changes occurred after the year 2003 with its extreme warm and dry summer. These changes are still ongoing, even if recently – as a consequence of an increasing precipitation (see tab. 2) – some waters recovered (see also fig. 3).

Still it is unclear, if and to which extent the extraction of ground water has additional impact on the wetlands. Hydrologists calculated a maximum additional lowering of the ground water table of 10–20 cm per year, which is much lower than the effects of a lack of precipitation. Thus they assume that extraction only has a minor effect (L.U.P.O. 2009). On the other hand, each additional lowering of the water table in the open waters as well as the ground water dependant ecosystems (GWDE) will prolong the periods of drought and consequently the stress on the species and ecosystems increases.

The "Kolbenwoog": an example for the effects of the extreme summer of 2003

During the summer of 2003 with its lack of precipitation the water table of the Kolbenwoog dropped and in the beginning only the shallow silted-up zone fell dry. This

Table 2. Important abiotic factors in the monitoring area: temperature and precipitation – extremes (>± 50% of mean per month) shaded in grey; l.-t.-mean = long-term mean (source: www.agrarinfo.rlp.de)

precipitation in [mm]	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	l.-t. mean
January	71	50	39	85	50	84	95	39	22	64	50	46	52
February	7	57	78	50	155	13	27	41	30	96	48	55	50
March	59	79	59	182	70	15	38	38	65	84	106	59	46
April	17	59	35	80	44	28	39	98	34	1	61	43	44
May	39	55	153	18	129	99	63	63	93	83	62	29	66
June	65	62	36	54	41	29	56	45	35	126	99	110	72
July	61	87	178	64	100	44	62	67	48	80	34	143	62
August	18	51	85	129	108	32	132	60	189	69	57	34	76
September	45	44	67	98	41	46	38	68	65	63	59	35	52
October	97	51	59	47	143	53	55	48	86	13	70	59	43
November	85	11	55	123	104	50	36	45	32	43	25	81	61
December	72	40	123	62	65	38	31	62	39	77	44	99	63
total / year	620	772	940	982	1051	530	673	672	738	799	713	793	692

Figure 3. Silt-up zone of the Kolbenwoog with rich – and now dry – vegetation: this important zone for larval development of sensitive species fell dry for years. Foto: J. Ott

zone is very important for the larvae of many dragonfly species: here they can hide and escape predation (in particular the sensitive *Leucorhhinia*-larvae – compare: Henrikson 1988). Also oviposition of many species takes place in these parts of the water with rich structured vegetation along the shoreline.

But also in the consecutive 3 years precipitation was very low (see tab. 2) and consequently the water level continued to fall. In summer 2006 the whole lake was nearly dry: only about 20 sqm of shallow water (nearly 40°C water temperature, no oxygen – own measurments) were left (see fig. 4). At this moment the water surface of the lake was reduced to ca. 0.25% (0.8 hectares under normal conditions) and the water body was reduced to ca. 0.07% (ca. 5400 cubic meters under normal conditions).

This nearly dry lake (see fig. 4), now having wide open shores with only scarce vegetation was colonized by several species, previously not registered at this water before: *Orthetrum cancellatum* (Linnaeus 1758), *Libellula depressa* Linnaeus 1758, *Gomphus pulchellus* Selys 1840 and also a few individuals of *Crocothemis erythraea* appeared. These species are typical for dynamic or secondary biotopes like gravel pits etc. and here – at dystrophic water bodies with mooreland biotopes (mires and bogs) – can be described as disturbance indicators.

Figure 4. The Kolbenwoog in July 2006: a dystrophic water nearly dry with wide open shores and no more vegetation in the water body (left) and in 2010 with a recovered water level (right). Fotos: J. Ott

Also the immigration of *Anax imperator* was noted, which became much more abundant and also indigenous. It is well known that this species has aggressive larvae which without doubt can have a strong influence on the other dragonfly species (see e.g. Beutler 1985), as in general dragonflies are important and prominent parts of the aquatic food chain (Turner and Chislock 2007).

In the same time period the typical mooreland species – *Coenagrion hastulatum* (Charpenties, 1825), *Somatochlora arctica* (Zetterstedt 1840), *Aeshna juncea* (Linnaeus 1758), *Leucorrhinia dubia* (Vander Linden 1825) – left the water and still did not return, even although the water table in the meantime recovered to its former level (see fig. 4).

For these species the Kolbenwoog lost its value, as the water was like a "small bathtub" with wide open shores and all the important habitat structures for larval development were gone: there were no more roots or other dense vegetation left, where larvae could hide or live and where the adults of the endophytically ovipositing species could lay their eggs (see fig. 3 and 5, also compare e.g. Henrikson 1993). It is well known and documented in many cases, that the complexity of the habitat structure is of general importance for the success of predators (see e.g. Warfe and Barmuta 2004).

Obviously this was a *tipping point* for the dragonfly community and it changed fundamentally.

Changes in other waters bodies

A similar change of the dragonfly fauna was observed in all the other waters of the three valleys of the monitoring area, only in two waters of the Erlental a small population of *Coenagrion hastulatum* and *Leucorrhinia dubia* survived (see fig. 5). *Somatochlora arctica* was not registered anymore and became extinct in the monitoring area, whereas *Aeshna juncea* disappeared also as an indigenous species, only single dispersing individuals were registered, but no population was left.

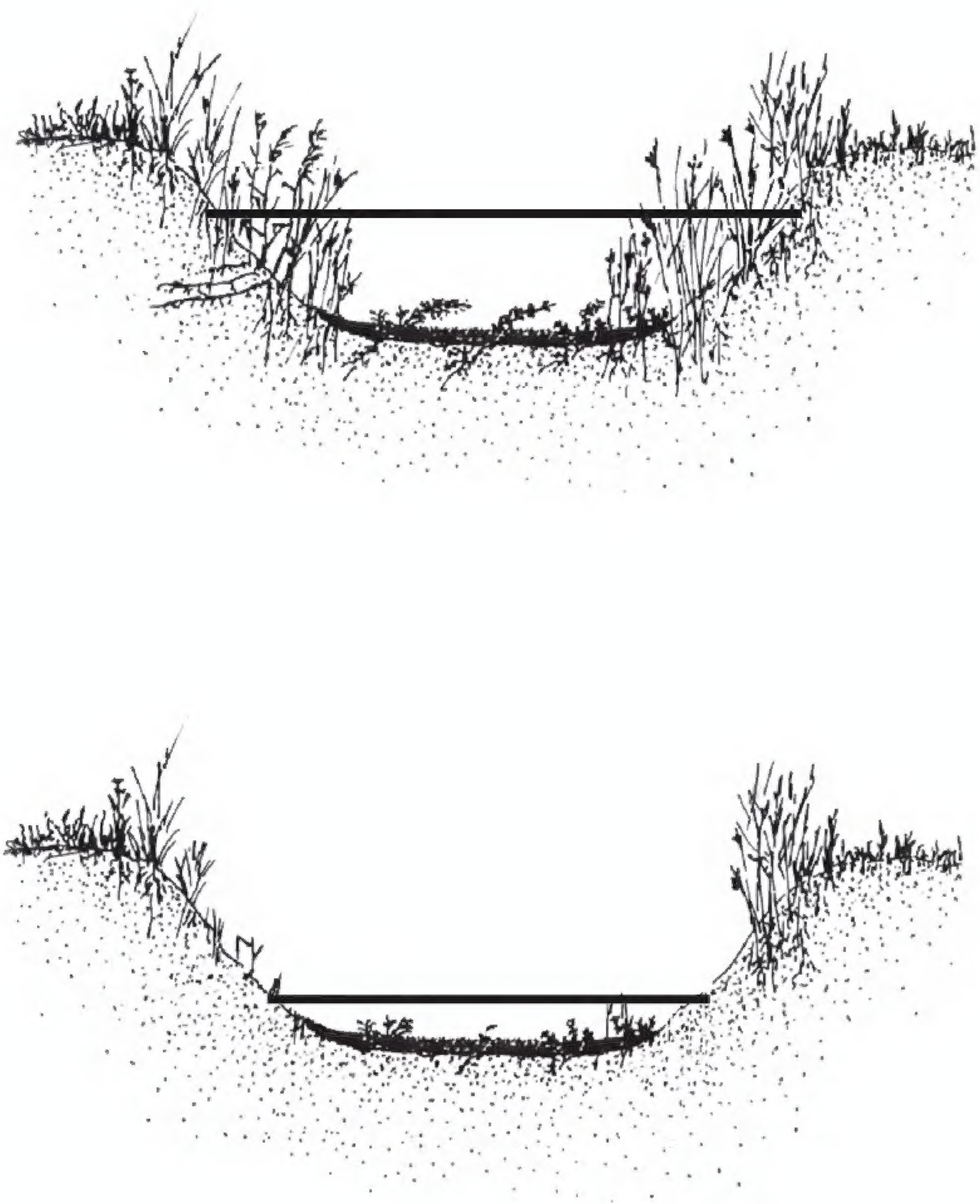

Figure 5. Different situations of the water – high and low water level (original)

As these two species in general became very rare in the Palatinate and the adjacent regions with only very few isolated populations remaining (see Ott 2006a, 2007b, 2007c, in press; Trockur et al. in prep. – see fig. 7) such extreme events may lead to a general extinction of the species on the regional level in the medium term.

A species which on the other side was profiting from this situation was the damselfly *Ischnura pumilio* (Charpentier 1825): all over the Palatinate it colonized these waters with open shores and extremely low water tables (Ott 2008b). Future investigation must show, whether this colonisation is successful for a longer period or whether the species becomes rare again, as it is normally found only in secondary waters.

Changes in the composition of regional faunas

The southern species did not only expand their range, they also increasingly dominated the regional faunas, as will be shown with the following examples.

	waters or valleys				
species present in 1998–2007	Gelterswoog	Rotenwoogtal	Kolben-woog / Kolbental	Erlentalweiher	Walk-mühltal
C. hastulatum	●●●●●-----	----------	●●●●●●●---	●●●●●●●●■■	●●●●●-----
S. arctica	----------	●●●●●-----	●●●●●-----	----------	----------
L. dubia	----------	----------	●●●●●■■■--	●●●●●●●●■■	-------●--
O. ceorulescens	----------	●●●●●●●●●●	---------- ?	●●●●●●●-●●	----------

● population
■ single individuals
- no record

Figure 6. Changes of the dragonfly fauna in the monitoring area: decrease of the mooreland species between 1998 and 2007 (each sigh represents one year).

First Example: Anisoptera of Mediterranean origin in the Palatinate

Table 3 shows the change in the dragonfly fauna (Anisoptera) in the last four and a half decades in two different but neighbouring regions of the Palatinate (= part of the federal state of Rhineland-Palatinate). Whereas in the mid 1960ies the dragonfly fauna in the lower situated and warmer “Vorderpfalz” was already a mixture of Mediterranean and Eurosiberian elements, in the cooler and higher Westpfalz it was still dominated by Eurosiberian species (see Itzerott 1965). For the author this was a normal and typical situation and the fauna was indicating very well the different climatic frame conditions.

About 30 years later the Westpfalz faced a big change: the species numbers increased and the Mediterranean species reached nearly the same percentage as in the “warmer” Vorderpfalz; at the same time temperatures increased about one to two degrees in the formerly “cooler” Westpfalz (Ott 1996, 2001a)!

Again fourteen years later in 2009 the situation did not differ that drastically anymore, but some changes still have been observed (Trockur et al. in prep.; Ott unpubl. data). Besides some turnovers a slight increase of species numbers in total could be registered. In the Vorderpfalz three new species were found in the meantime: *Leucorrhinia rubicunda* (Linnaeus 1758), *L. caudalis* (Charpentier 1840) and *Stylurus flavipes* (Charpentier 1825). The latter two species are also autochthonous. In the Westpfalz *Epitheca bimaculata* (Charpentier 1825), *Somatochlora flavomaculata* (Vander Linden 1825) and *Libellula fulva* O.F. Muller, 1764 were new.

Interestingly all new species are Eurosiberian elements, but this does not mean the start of a return to a former situation: looking at the details it is more a stabilisation of the situation. As shown before – see e.g. fig. 6 – especially the Eurosiberian elements became much rarer and were found in fewer sites. In the central Palatinate forest, a part of the Westpfalz, some Mediterranean species now are definitely or probably indigenous, like *Crocothemis erythraea* or *Ashna affinis* (Ott 2010b).

Table 3. Changes in the Anisoptera fauna of two regions in the Palatinate: V = Vorderpfalz, W = Westpfalz, Med E = Mediterranean Elements, Eurosib. E = Eurosiberean Elements (1965: Itzerott 1965, 1995; Ott 1996, 2009; Trockur et al. 2010, Ott unpubl. data).

year	area	dragonflies		
		no. species	Med. E (%)	Eurosib. E (%)
1965	V	29	55	45
	W	16	31	69
1995	V	33	52	48
	W	30	47	53
2009	V	34	47	53
	W	34	44	56

In this context it must be considered, that this analysis is only done for the Anisoptera but not for the Zygoptera (as Itzerott 1965 published only on the Anisoptera and no data for Zygoptera are available in this detail). Within the Zygoptera quite some expansions of Mediterranean elements in the central Palatinate were registered in recent years, like for *Lestes barbarus* (Fabricius 1798), *Ischnura pumilio* and *Coenagrion scitulum* (Ott 2006b, 2008b; Lingenfelder 2008).

Second Example: the odonatofauna in the SLL+-region

Recently the dragonfly fauna of the so called SLL+-region – consisting of the two German federal states Saarland and Rhineland-Palatinate, as well as Luxembourg, the French department Lorraine and the Belgian Wallonia – was investigated and analysed for an atlas project (Trockur et al. in prep). In this area, covering 65,401 sqkm, also the southern species increased in abundance and enlarged their ranges. When comparing the situation before and after 1990, many southern species increased in the numbers of grid cells where they were found (e.g. *Crocothemis erythraea* + 109, *Erythromma viridulum* (Charpentier, 1840) + 107, *Aeshna mixta* Latreille, 1805 + 73, *Anax imperator* + 72). Also species like *Anax parthenope, Sympetrum meridionale* and *Sympetrum fonscolombii* became more abundant and very recently another damselfly - *Coenagrion scitulum* - showed a remarkable expansion (Lingenfelder 2008), being new for many parts of the area.

If this trend continues, without any doubt more species with a Mediterranean origin will appear in the near future, like *Boyeria irene* (already present near Lake Constance - see Schmidt 2005 or in the French Departement Haute-Marne – see Ternois 2008), *Anax ephippiger* (Burmeister, 1839) (already appearing several times as a guest – see Schorr 1989) and even the African *Trithemis annulata* (Palisot de Beauvois, 1805), which is expanding in southern France and now was also found in Lombardy (Boudot et al. 2009).

On the other hand Eurosiberean elements decreased (e.g. *Lestes sponsa* (Hansemann, 1823) - 39, *Coenagrion hastulatum* - 31). Especially *Coenagrion hastulatum* is facing a strong decrease in the Palatinate (see fig. 7); obviously the species is very sensi-

tive to lowered water tables. Some species even seem to be close to extinction, as their populations are very small, the quality of the biotopes is poor (moorelands already degraded) and the distances between the remaining biotopes are very long (high degree of fragmentation); this is in particular true for *Somatochlora arctica* (Ott 2006a), but also some other species face a similar – only slightly better – situation (*Aeshna juncea, Leucorrhinia dubia*, see Ott in press).

More examples: the odonatofauna in Bavaria and North Rhine-Westfalia

The same trends – increase of southern species, often accompanied by the decrease of mooreland species – were registered in several other federal German states or regions.

In a region of Bavaria (Nordwest-Oberfranken) investigations on the dragonfly fauna started in the 1970ies by the Bund Naturschutz (NGO in nature conservation). In the last years observations of a decrease in mooreland species increased. In 2006 all available old data were analysed and compared with data collected in this year (ÖBO 2007). If possible, the same waters as in former times were investigated to have a direct comparison. For this study a total of 41 water bodies were assessed.

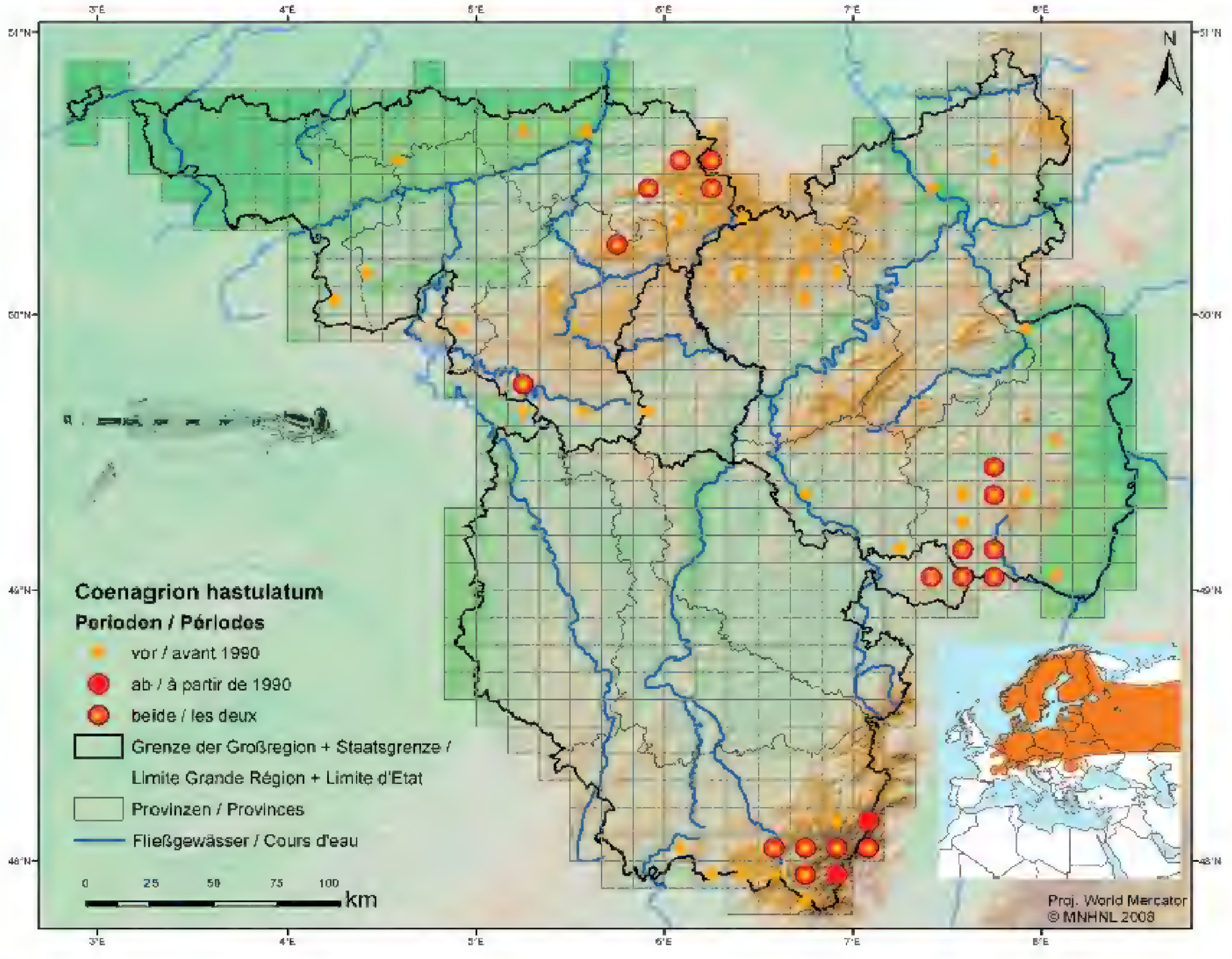

Figure 7. Distribution of the mooreland species *Coenagrion hastulatum* and *Somatochlora arctica* in the Sar-Lor-Lux-plus-region (Trockur et al. in prep.)

For the first time ever in this area *Crocothemis erythraea* was found now, which in two cases also appeared in typical mooreland waters, together with *Leucorrhinia dubia*. The latter species could not be registered anymore in half of the formerly populated waters, and *Aeshna juncea* disappeared even from 60 % of the waters colonised in the 1980ies and 1990ies. Also *Coenagrion hastulatum* dissapeared from 50 % of the formerly populated waters; in particular from the waters below 350 a.s.l. *Leucorrhinia rubicunda* (Charpentier 1825) was not found anymore, *Leucorrhinia pectoralis* also vanished from all its former waters and for *Somatochlora arctica* only one observation was made. So all mooreland species showed a strong decrease, whereas on the other hand *Crocothemis erythraea* now was found in three mooreland waters; the authors see the climatic changes as the reason for this change in the dragonfly fauna, as until today the main effects occurred mainly in the climatically favourable lowlands.

For the federal state of North Rhine-Westfalia the increase and spread of thermophilous dragonflies in recent decades is shown by Conze et al. (2010) through an analysis of about 150,000 data sets which were collected by a working group. Also in this case *Crocothemis erythraea* was the "leading" species.

Aspects of nature conservation

Biodiversity increase and consequences for the Red Lists

In the past decades biodiversity on all levels faced a more or less strong decrease, which is documented in the red lists of species and biotopes. If new species now arrive in an area, biodiversity – if we look only at the number of species – increases. To maintain a high biodiversity is one of the goals of nature conservation in general, and consequently the present situation should be regarded as positive and desired, also if we look at the fact that many southern species were on the last red list while now in the updated version many of them could be taken off (Ott and Piper 1998; Ott et al. in prep.).

But we still do not know, whether in the medium or long term, at least on a regional scale, biodiversity will rather decrease. As shown by the examples in Bavaria, the Palatinate or the SLL+region, in particular species of mooreland biotopes, which are more sensitive or stenoecious, seem to suffer from the present climatic situations (increased temperatures, falling water tables, drying out of waters, invasion of other species, e.g. with aggressive larvae). Beside the mooreland species also the alpine species are at risk: when looking at scenarios of future development for many regions, these species may not survive the next decades, as e.g. in Germany many regions will see some kind of "mediterranisation" of the climate (lack of water in the summer and higher temperatures). In particular the small water bodies in higher altitudes may easily dry out for a longer period, which most probably will lead to the extinction of many alpine dragonfly species.

After some increase in dragonfly biodiversity on the national level – as a consequence of the invasion of southern species – biodiversity will probably decrease, as we will lose the mooreland and alpine species.

Effects on the Natura 2000 web in the Palatinate forest

This decrease of biodiversity will probably also take place at the landscape level: due to the lack of water in extreme warm years many waters lost their habitat suitability (see fig. 8) and thus the species indicating the typical communities of the Natura-2000-biotopes (according to Ssymank 1998). This is shown in tab. 4: whereas two decades ago the typical species were still present (see Niehuis 1984), in recent investigations they only could be found in significant fewer numbers or even could not be found anymore at all (Ott 2007b, in press).

The species *Aeshna juncea, Leucorrhina dubia, Coenagrion hastulatum* only survived in very few and small populations, they could be classified as loser; for *Somatochlora arctica* only one single population is left in the whole German part of the Biosphere reserve Pfälzerwald-Vosges du Nord (Ott 2006a, 2010b, see also fig. 7).

Interestingly, several populations of these endangered species are not found in reserves or protected biotopes – dragonflies should be integrated more in reserve planning, what was recently also suggested by Heino et al. (2009), who showed that many protected areas were not delineated based on the requirements of freshwater organisms.

In principal the recolonisation of the waters from the French part of the reserve, the Vosges du Nord, is always possible, as there the situation seems to be still better

Table 4. Dragonfly fauna in some waters of the Natura 2000 web in the biosphere reserve Palatinate Forest (A = 1980-1995; B = 2005-2007, water table: + = intact, - = lowered, **O** = present/population, **O**[1] = present/single individuals; * = a little outside of the reserve; species shaded = disturbance indicators).

waters	Jagdhaus-weiher		Vogelwoog *		Pfälzerwoog		Rösselsweiher		Kranzwoog	
time span	A	B	A	B	A	B	A	B	A	B
water table	+	-	+	-	+	-	+	+	+	-
species										
P. nymphula	O	O	O	O	O	O[1]	O	O[1]	O	O
C. hastulatum	O		O		O		O		O	
A. juncea	O		O		O		O		O	
S. arctica	O									
L. dubia					O		O		O	O[1]
L. pectoralis										
S. danae	O	O	O		O	O	O	O	O	
L depressa		O	O	O	O	O				O
O. cancellatum		O	O	O	O	O		O		O
G. pulchellus		O		O		O		O		

Figure 8. The nature reserve Pfälzerwoog; in August 2006 the water fell nearly completely dry. Foto: J. Ott

for mooreland species (Duchamps and Morelle, pers. comm.). But on the other hand the waters in the Palatinate now have another abiotic quality and other communities are now established (see the example of the monitoring-project Kolbenwoog), consequently the dystrophic waters lost or will loose their characteristics. Without doubt this also will have consequences for the ecosystem services of these waters (water retention, landscape aesthetics etc.) and other – already existing impacts (fragmentation, lowering of the groundwater table) – will have additional effects.

Changes on the national level: some recent trends in Germany

Changes in the phenology

In general insect species react on the increase of temperature with a change in their phenology: increasingly observations are made very early or very late in the season. This process started in the 1990ies, since then with an increasing number of such observations.. Here some recent data for Germany are summarized.

E.g., in mid December 1994 *Sympetrum striolatum* was still on the wing in Switzerland and in early November 1999 *Lestes sponsa* (Hansemann 1823) in Baden-Württemberg (Jödicke 2000). In 1994 and 1997 *Somatochlora metallica* was on the wing

until October (Reder 1997) while in 2000 *Gomphus flavipes* was registered in the Rhine Valley still in mid October (Reder 2001).

Extremely early and warm springs – like in 2007, one of the warmest years since climatic data are registered in Germany – did have an additional effect on the phenology: in Baden-Württemberg more than 30 species emerged earlier than ever registered before (Hunger 2007). Some for only a few days, but many species emerged even one (e.g. *L. barbarus, E. najas* (Hansemann 1823), *L. caudalis* (Carpentier 1840)), two (e.g. *C. hastulatum* and *pulchellum* (Vander Linden 1825), *C. aenea* (Linnaeus 1758)) or even three weeks (*L. dubia*) earlier then ever observed before.

Sometimes very late emergences are registered recently for *Gomphus vulgatissimus.* Niehuis and Heilig (2004) found a fresh individual on the 29th of July 2004 in southern Palatinate, where the flight period in general lasts only until late June and Westermann (2002) found an eclosing male on the 9th of August 2002 in Baden-Württemberg.

For the Lausitzregion in eastern Germany Donath (2009) compared the data of the first emergence: he could present several records of extreme early emergence from 2009 and by comparing this situation with the year 1977 he could also show a general trend of an earlier emergence of about one week. Some species like *Coenagrion pulchellum, Orthetum cancellatum, Leucorrhinia dubia* and *Lestes dryas,* Kirby 1890 emerged even two weeks earlier in 2009 – with the warmest April at least since 1891.

Besides a prolonged phenology of the adults also an impact on the eclosion period was registered which is indicated by very late and "not normal" eclosion: at the end of September 1999 a teneral male of *Gomphus vulgatissimus* was seen in Lower Saxony (Fliedner and Fliedner 2000). In Baden-Württemberg 33 individuals of *Lestes sponsa* emerged during the first week of September 2005 (Koch 2005).

In the mid or long term this might lead to a desynchronisation in the phenology. It is well known that thermal impacts on waters – e.g. by power plants – lead to earlier eclosion, even in winter. Consequently, also the general increase of the temperature will most probably have the same effect.

More generations: from semi- to univoltine, from uni- to bivoltine

A wide range of species now has a second generation: in Germany species which formerly were univoltine now became bivoltine, or migrating species had a second generation. In the mid 1990ies this was only registered for a few species and areas, like for *S. fonscolombii* in Bremen, Lower Saxony and northern Hesse (e.g. Pix 1994), or *Ischnura elegans* and *I. pumilio* in North Rhine-Westfalia (Inden-Lohmar 1997). In the consecutive years this phenomenon became much more widespread and was seen in an increasing number of species, as well as all over Germany. E.g. it was shown for *E. cyathigerum*, *E. najas*, *I. elegans* and *S. fonscolombii* in Baden-Württemberg (Schiel 2006; Koch 2002), and for *I. elegans* and *pumilio*, *E. najas* and *S. fonscolombii* in Bavaria (e.g. Burbach 2000). In Rhineland-Palatinate *I.pumilio* and *E. cyathigerum* in some years do have a second generation (Ott 2008b, unpubl. data).

Especially in hot summers, like the one in 2003, this effect is apparent and even the Mediterranean *Crocothemis erythraea* might have a second generation in Germany (Horn 2003). In some years (1999, 2000, 2006) this was also shown for *Anax imperator* in southern Germany in four localities, the species generally is known to be bivoltine only for the Mediterranean (Westermann and Weihrauch 2007).

Species formerly not known to have a univoltine cyclus in Central Europe, like *Gomphus pulchellus* and *Leucorrhinia caudalis*, show it now in southern Germany (Schirrmacher et al. 2007) or partly, like *Leucorrhinia pectoralis* and *Brachytron pratense,* in north-eastern Germany (Brauner 2006).

Moving to higher altitudes

Anax imperator is in general a lowland species, but recently also can be found in altitudes of more than 1000 m a.s.l. (Hunger et al. 2006) and even on 915 m a.s.l. an indigenous population was registered (Westermann 2003c). But also damselflies move to higher altitudes, *Lestes viridis* (Vander Linden 1825) in general found in the lowland is found breeding in 900 m a.s.l. (Westermann 2003a). Also *Lestes barbarus* was found in the Black Forest regularly up to 700 m a.s.l. where it is also breeding in some cases (Hunger et al. 2006; Salcher 2006), in the Palatinate it populated the higher centre expanding from the lowlands and is now found breeding in altitudes of ca. 400 m a.s.l. (Ott 2006b). Again in the Black Forest at an altitude of 1010 m a.s.l. another damselfly – *Erythromma najas* – was found indigenous, which represents the highest reproduction site in Germany so far (Westermann and Westermann 2003) and in 2005 the highest elevation of an autochthonous population in central Europe was registered for *Gomphus pulchellus* (Selys 1840) (Westermann 2006). This western Mediterranean species started its east and northward expansion already in the last decades (Rudolph 1980) and now – besides the continuation of this expansion – also moves to higher elevations.

Changes on the European level – some recent trends

Even if the expansion of damsel- and dragonflies on the European level are not demonstrated for all countries in a totally comparable way – as in many countries data collection is done in a different way and intensity – the general pattern however is very obvious.

To compare this trend the situation in the early/mid 1980ies is taken from Askew (1988) who for the first time presented maps on the European distribution. For the situation in 2009 data and information were taken from different publications and national atlas projects (e.g. Nielsen 1998; NVL 2002; Karjulainen 2002; Nelson and Thompson 2004; Grand and Boudot 2006; Parr 2003, 2004, 2005, 2006, 2007, 2008, 2009; Bouwman et al. 2008; Dolny et al. 2008; Bernard et al. 2009), as well as websites of the national odonatological societies.

Table 5. Damselfly and dragonfly species of Mediterranean origin in 2009: showing clear northern range expansions in Europe compared to Askew (1988).

Species name	Range expansion in
Ischnura pumilio	New for Sweden in 1992, remarkable increase from 2007 onwards
Coenagrion scitulum	France, Germany, Belgium, Luxemburg, also in the East, e.g. in the Czech Republic
Erythromma lindenii	North-eastern France, parts of Belgium, northern and eastern Germany, new to UK
Erythromma viridulum	North-eastern France and Netherlands (now very common and present on all Wadden islands), northern Germany and also in Poland: here it expanded in the last 3 decades up to 300 km; in 1999 new to the UK, here spreading quickly in the south-east, obviously in "waves"; new to Denmark, between 2001 and 2009 already found in 53 localities, in 2004 new to Sweden and in constant expansion in the south
Lestes barbarus	Central parts of Europe, becoming more abundant, new to the UK
Aeshna affinis	Northern France and Germany, Netherlands. New to the UK (possible sighting in 1993, then e.g. in 2004 and 4 times in 2006), Denmark (2 records for 2006) and Finland (1 male in 2008)
Aeshna mixta	UK up to the central parts, in Poland significant increase and area of native occurrence has expanded 350 km northwards; new to Ireland, Sweden and Finland; in Finland first recorded in 2002, now a rare breeder in the south, in Sweden also larvae were found and in particular in 2007-2009 a high number of observations
Anax imperator	Obviously in many countries increasing, e.g. Germany and Poland, here rare about 100 years ago, but now widespread, also in higher elevations; UK up to the central parts and new to Scotland, also new to Ireland, Denmark and Sweden; in Denmark first recoded at the end of the nineties, but in the last 10 years recorded in more than 200 localities; in Sweden spreading very quickly northwards (> 700 km), after being recorded in 2002 for the first time
Anax parthenope	Northern France, Belgium, Netherlands, northern Germany and Poland, new to UK (first recorded 1996, Gloucestershire; has bred in Cornwall, record year in 2003 and increasing numbers between 2005 and 2007: in more than 60 sites) and also Ireland
Boyeria irene	North-eastern parts of France, new to Germany
Gomphus pulchellus	Northern and eastern parts of Germany, also to Austria
Oxygastra curtisii	Rediscovered in Germany after more than 50 years
Crocothemis erythraea	All central Europe, new for the UK in 1995
Sympetrum meridionale	All central Europe, up to northern Germany and Poland
Sympetrum fonscolombii	New to Denmark, between 2003 and 2009 found in 9 localities, new to Sweden, found in 1997, 2003 and 2007
Species name	**Increasing tendency of migrations/invasions, e.g. observed in**
Anax ephippiger	Germany, in some years even reproducing; other central European countries (e.g. Poland)
Sympetrum fonscolombii	UK, Ireland, northern France, Belgium, Netherlands, Germany, Poland, partly indigenous populations (second generation)

Especially when looking at the northern European countries, expansions from the south are obvious, or at the "other end of the continent": at the southern countries, where recently African species expand to the north as well (see below).

In Sweden for example beside the above mentioned new species others – which were already present in low numbers – currently expand in a remarkable way, like *Calopteryx splendens* (Harris 1782), *Libellula depressa* (Linnaeus 1758) and *Sympetrum striolatum* (Charpentier 1840). The same trend is seen in the UK, where species formerly mainly restricted to the south – e.g. *Libellula depressa* and *Orthetrum cancellatum* – expanded northwards. *Libellula depressa* reached Scotland where it was first recorded in 2003 and again twice in 2007 (Parr 2004, 2007).

In Poland *S. meridionale* (Selys 1841), *S. fonscolombii* (Selys 1840) and *striolatum* are now „normal" elements of the fauna, formerly they were rare and species like *Crocothemis erythraea* and *Orthetrum albistylum* are moving northwards (Bernard et al. 2009).

New for Lithuania in 2003 became *Aeshna affinis* Vander Linden, 1820 (Bernard 2005), which is very likely to be also indigenous. For Latvia in 2008 *Anax parthenope* was registered for the first time and in 2008 and 2009 it was found in five localities (Kalnins 2009), where in one case it also eclosed. In Belarus several species are now new to the national fauna and/or expanded, like *Sympecma fusca* (Vander Linden 1820), *Lestes viridis, Erythromma viridulum, Orthetrum brunneum* and *O. albistylum* (Selys 1848) (Buczynski and Moroz 2008).

On the other hand in the Mediterranean countries we can observe a recently started process: the expansion of African species as shown in table 6 (again compared with Askew 1988; the present situation according to the websites mentioned above and Boudot et al. 2009).

The Violet Dropwing (*Trithemis annulata,* see fig. 9), a typical species all over Africa and the Middle East, formerly occurred only up to southern Spain and central Italy (Askew 1988). But now it can be found even in southern France, having crossed entire Spain and also the Pyrenees and in Italy it now reached the area of Ferrara (Boudot et al. 2009). Another *Trithemis* species – the afro-tropical Orang-winged Dropwing (*Trithemis kirbyi* Selys 1891) – was not known for Europe at all, but then was discovered for the first time on the isle of Sardinia in 2003 (Holusa 2008). After being discovered in 2007 also in southern Spain near Malaga by D. Chelmick, in 2008 for the first time larvae of this species were found proofing its first autochthony in Europe (Cano-Villegas and Conesa-Garcia 2009).

The third example of an African respectively Asian species expanding its range to the north is the Black Pennant (*Selysiothemis nigra* Vander Linen 1825), which in Italy is actually found up to the area of Trieste/Venice (Boudot et al. 2009) in the eastern part and up to Parma (M. Salvarani pers. comm.) in the western part.

Figure 9. A male of the Orange-winged Dropwing (*Trithemis kirbyi*): new in Europe. Foto: J. Ott.

Table 6. African species recently expanding in Europe

Species name	Range expansion in
Trithemis annulata	Spain (entire country crossed), Italy (up to Lombardy) and France (only in the south)
Trithemis kirbyi	New to Spain (also indigenous, in the area of Malaga) and Italy (Sardinia)
Selysiothemis nigra	Now present in northern Italy (near Parma in the west and Venice in the east), northern Spain (close to the French border) and Slovenia

Biological effects - Climatic change: a filter for different ecological strategies and species

The biological effects of the rise in temperature for Odonata could be summarized as follows (updated from Ott 2001a; see also Hickling et al. 2005; Corbet et al. 2006; Dingemanse and Kalkman 2008; Hassel and Thompson 2008):

- more prominent tendency for expansion
- more northerly breeding, also breeding in higher altitudes
- changes in the composition of the fauna
- eclosion earlier in the season, overall alteration in the phenology
- second generation, changes in voltism
- more rapid larval development

The tendency for expansion is in particular notable in warm years like 2003: see in this context e.g. Parr (2004, 2007, 2009) where many species were seen far away from known breeding sites (*Erythromma viridulum*: ca. 100 km, *Brachytron pratense*

Table 7. Winners and losers of climatic change (Ott 2001a, updated).

winner	loser
species with preferences for higher temperature	species with preferences for lower temperature
"lowland species"	"mountain species"
common and widespread species	locally distributed / rare species
species of eutrophic waters	species of oligotrophic waters
euryoecious / ubiquitous species	stenoecious species
good flyers	bad flyers
fast / short larval development	slow / long larval development
r - strategists	K - strategists
species with aggressive and / or temperature-tolerant larvae	species with "sensitive" and / or temperature-intolerant larvae
examples: *Ischnura elegans, I. pumilio, Lestes barbarus, Libellula depressa, Crocothemis erythraea, Anax imperator*	examples: *Coenagrion hastulatum, Somatochlora arctica, S. alpestris, Aeshna subarctica, Leucorrhinia albifrons*

(O.F. Müller 1764): ca. 100 km, *Cordulia aenea*: > 100 km, *Orthetrum coerulescens*: 20–30, even up to ca. 45 km).

Finally climatic changes can be regarded as a filter: they favour the species which are able to adapt to the new situations (higher temperatures, drying out of waters etc.) and eliminate the species which cannot cope with the new environmental conditions. There are winners and losers of the situation.

The future is … hot?! What do scenarios tell us and what does this mean for dragonflies?

Even if in some countries (e.g. Germany) or even in the entire EC the emissions are stable or reduced (see EEA 2009a), worldwide emissions of carbon dioxide and other greenhouse gases will still be increasing (IPCC 2007a).

Assuming that these gases are the reasons for the climatic changes (on which there is a general agreement within the scientific community), the changes of the abiotic conditions (e.g. temperature increase, changes in the precipitation) will go on, as well as the effects on the biotopes and communities.

The different scenarios – like the ones which are used by the IPCC (IPCC 2007a) or the ones in the ALARM-project (Settele et al. 2010a, 2010b) – expect that there will be an additional increase of temperature of at least 2 degrees within the next decades, some scenarios expect an even higher increase.

This means that all the shown conditions for dragonflies in Europe, e.g. higher temperatures in the waters, lack of the precipitation in summer, falling water tables,

higher air temperatures, more sunshine etc. will continue and become even more intense in the future.

As the range expansions to the north demonstrated here (see tab. 6) were the results of only an increase of about 1° Celsius in Central Europe in the last decades, in the future the changes of the waters and their communities – higher proportion of thermophilic and southern species etc. – could be expected to be even stronger and faster, finally these species will dominate the dragonfly fauna.

However, also some Mediterranean species in the medium term may loose large parts of their distributional area in the south, as in particular in the Mediterranean many waters will dry out and so lose their biotope quality in general for aquatic species (see August and Geiger 2008; Ott 2010a).

The effects of climatic changes in the Mediterranean will however be much stronger on other taxa, like the Trichoptera and Plecotera, as these taxa have many endemics (Hering et al. 2009; Tierno de Figueroa et al. 2010).

On the European level there might be little concern for most of the southern generalist dragonfly species level, while on the other hand the species of moorelands, higher altitudes and colder biotopes will continuously be eliminated, as in particular these biotopes will suffer in the next decades (Ott 2001a, in press). In higher areas biodiversity will increase as a result of the "invasion" of lowland species – see Oertli et al. (2008) and Oertli (2010) – but this will without any doubt have a negative effect on the more sensitive species of the mountains, which can not move any higher, as there are no more waters. In general mountains like the Alps or the Pyrenees will face strong impacts and changes of their water regimes (e.g. for the Alps: EEA 2009b) and in particular species with a small range and those which live in rare climates (e.g. interglacial relicts) will be reduced disproportionally (Ohlemüller et al. 2008).

Consequently these cold stenothermal species will be eliminated, which is also true for other sensitive species of the lower mountains or even the lowlands. In the Black Forest (see Hunger et al. 2006) *Aeshna caerulea* – a species restricted to peat bogs above 830 m a.s.l. – is more or less extinct, as the climatic circumstances became increasingly unfavorable for the species.

The same is true for *Aeshna subarctica* in northern Germany: their larvae are specialists of peat bogs, and monitoring studies in the federal states of Brandenburg and Mecklenburg-Vorpommern show their dramatic decrease (Peters 2008; Bönsel 2001). The reasons seem to be the eutrophication of the waters in general and the extreme summer heat in the waters, which has negative impacts on the larvae, as these have preferences for lower temperatures.

Furthermore there will also be many cumulative and synergistic effects, which hitherto have hardly been studied.

These factors are for example:

* acidification of the waters ("acid rain", impacts on the aquatic communities)
* eutrophication through immissions (leading to oxygen consumption, algal blooms and succession)

* (ground-)water extraction (lowering of water table, impacts on ground water depending ecosystems)
* higher concentrations of pollutants / toxic substances (mainly in the running waters) and also alien invasive species (alien crayfish, grass carps etc.) will play an increasingly important role.

For example the level – and thus also the lowering – of the groundwater determines the relative susceptibility of regions to changes in temperature and precipitation, ergo the extraction will be an additional and cumulative threat (see Maxell and Kollet 2008).

This might be the case for the example "monitoring Kolbental" which was shown here: if at the end the extraction has a negative effect on the groundwater level, the whole area with its biotopes will be impacted even more.

Another example is the increase of the water temperature of rivers: the mean water temperature in the river Rhine increased by 3 degrees during the last 100 years, 2 degrees as a result of cooling water discharge and another one as an effect of climatic changes (BUND 2009). But not only the mean water temperature increased, also the days with water temperatures above 23° and 25° C, and the probability of extreme high water temperatures, passing a critical – or tipping – point of 28 degrees, where many species (e.g. fish, molluscs) die and then cause "toxic waves" of ammonium etc., leading to other impacts.

These problems are reviewed and summarized for European rivers by WWF (2009), where it is shown, that the known and expected changes in the river temperatures do already have many ecological consequences – and will have even more in the future – as the communities of the waters are adapted to a certain temperature regime. Effects are posed on the abiotic conditions – e.g. lack or higher consumption rate of oxygen (Sand-Jensen and Pedersen 2005) – as well as on the composition of the communities (e.g. the mollusc fauna will be reduced: Mouthon and Daufresne 2006; the fish communities altered: Daufresne and Boet 2007). Finally complete food webs are changed (Emmerson et al. 2005).

It is also relevant that not only the general temperature increase will have an effect on the flora and fauna, but also the extreme situations (e.g. heat waves), which are expected to happen much more often (Daufresne et al. 2007).

This leads to another aspect: as shown before, temperature increase functions like a general filter (see tab. 7), but the increasing number of extreme events will function as a second filter.

Extreme climatic conditions – which used to be rare and localised – become more and more abundant and also new situations will occur, which until today did not happen at all (see Meehl et al. 2000 and Wigley 2009). This will lead to many impacts, also on the communities' level (see the above mentioned examples of the rivers, or Thibault and Brown 2008) and synergism of global warming and other stresses (e.g. habitat destruction) can disrupt the communities (Root et al. 2003).

Still it is unclear, whether the undoubtful increasing of the competition when new species arrive in a water body, also leads to an exclusion of the former fauna. This

might be in particular the case, when new biotope types are colonised: e.g. *Crocothemis erythraea* enters now acid waters (Ott 2010b), whereas the species formerly preferred secondary waters like sand- and gravel pits (Ott 1996) and now may use another niche (see here: Broennimann et al. 2007).

Emmerson et al. (2005) pointed out, that already small changes in the number of species in a food web can have consequences both for community structure and ecosystem processes, consequently community stability and ecosystem functioning is altered. In particular when a top predator arrives, what is shown by Byström et al. (2007): the extinction of the char was caused by the pike (trough predation and competition) which expanded to the north and effects on the whole food web were registered. Consequently, also effects on the dragonfly fauna of northern countries can be expected, even if there are still many open questions in community ecology (see Booth et al. 2009: what will be the effects of the changes in phenology on the different trophic levels?). Biotic interactions and feedback processes lead to highly complex, nonlinear and sometimes abrupt responses. To identify and quantify these processes remains a huge challenge (see Walther 2010).

Conclusions

In Europe, dragonflies have a moderate number of species, their ecology is mostly well known, and they are easy to identify, thus they are perfect indicators. This is in particular true – as shown here – for the effects of climatic changes on different levels (single waters, landscape or national / European level).

Contrary to other taxa they depend only on waters, which are more or less omnipresent, and their expansion is only due to their dispersal and migration behaviour. Butterflies depend also on plants, and if these do not expand their range, also the butterflies are unable to do so; grasshoppers are transported sometimes by vehicles and so their expansion is some kind of artificial. This makes dragonflies some kind of unique as climate change indicators.

Here it is shown that in the recent decades there were massive range expansions of damsel- and dragonflies in Europe, leading to changes in the communities. Climatic changes are the reason for these expansions, leading to a higher biodiversity in many areas, but they are also the reason that now some species are threatened or will be threatened in the future. This is in particular true for mooreland species and species of higher altitudes, in the future maybe also for species of springs or species of smaller running waters (mainly in the Mediterranean).

Climate change can be seen as a threat for the dragonfly fauna in addition to the impacts which already had been identified. Many synergistic and cumulative effects do occur and will do so even more in the future (e.g. lack of precipitation and an increase of water demand and consumption). Alien invasive species (e.g. fish, crayfish) might also play an increasingly import role.

The effects – most of them negative – for the waters and (dragonfly) communities have a consequence also for future strategies in nature conservation, as e.g. one of the

most important concepts to protect biodiversity in Europe – the Natura-2000-network might not work anymore, as these biotopes are increasingly detiorated and lose their function.

To follow these processes and to identify the effects of global change phenomena, it is of crucial importance to establish and maintain European wide data collections and monitoring schemes.

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